KO-US Collaboration Workshop, April 15~16, 2009, San Diego, U.S.A.

OVERVIEW OF KO FUSION PROGRAM

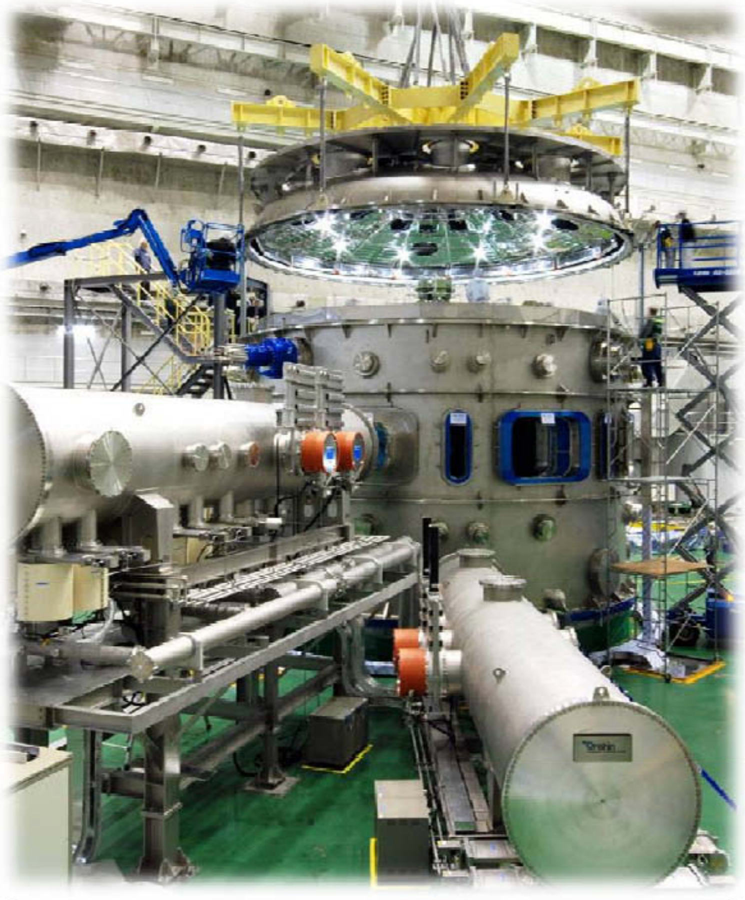
M. Kwon and Collaborators

National Fusion Research Institute

NFRI 국가핵융합연구소
National Fusion Research Institute

Outline

- Introduction
- KSTAR Program
- ITER-KO Program
- Collaboration & Outreach
- Summary

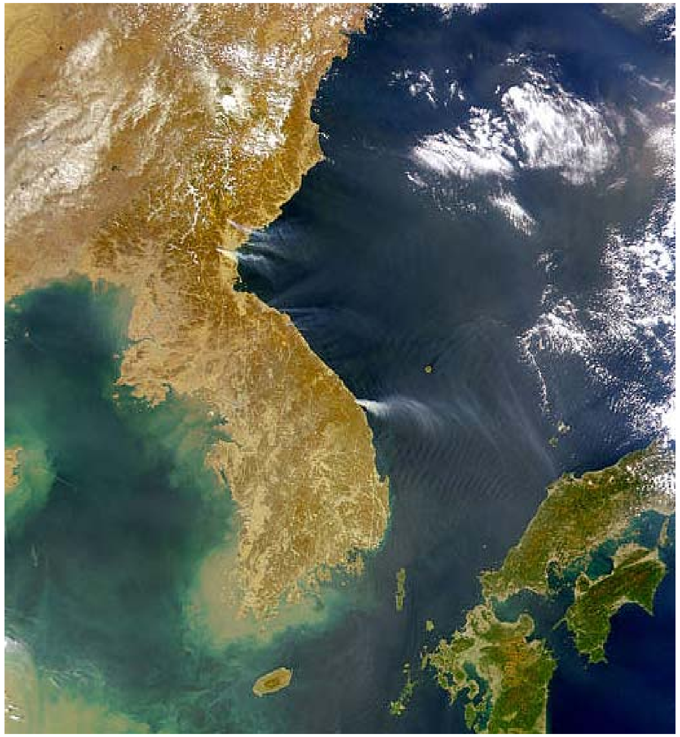


Energy Facts in Korea

- **Import most of energy sources mainly in the form of fossil fuel**
- **World's Top 10 energy consuming country**
- **Heavily dependent upon nuclear power (38 %) and fossil fuel (60 %) for producing electricity**

- Energy Import

  97 % of Energy Consumption



- Electricity Production
  - Hydro : 1.7 %
  - Nuclear: 38.2 %
  - Fossil : 60.1 %

Why Fusion for Korea ?

Korea, Poor Country in Energy Resources

- 97% of Energy Import

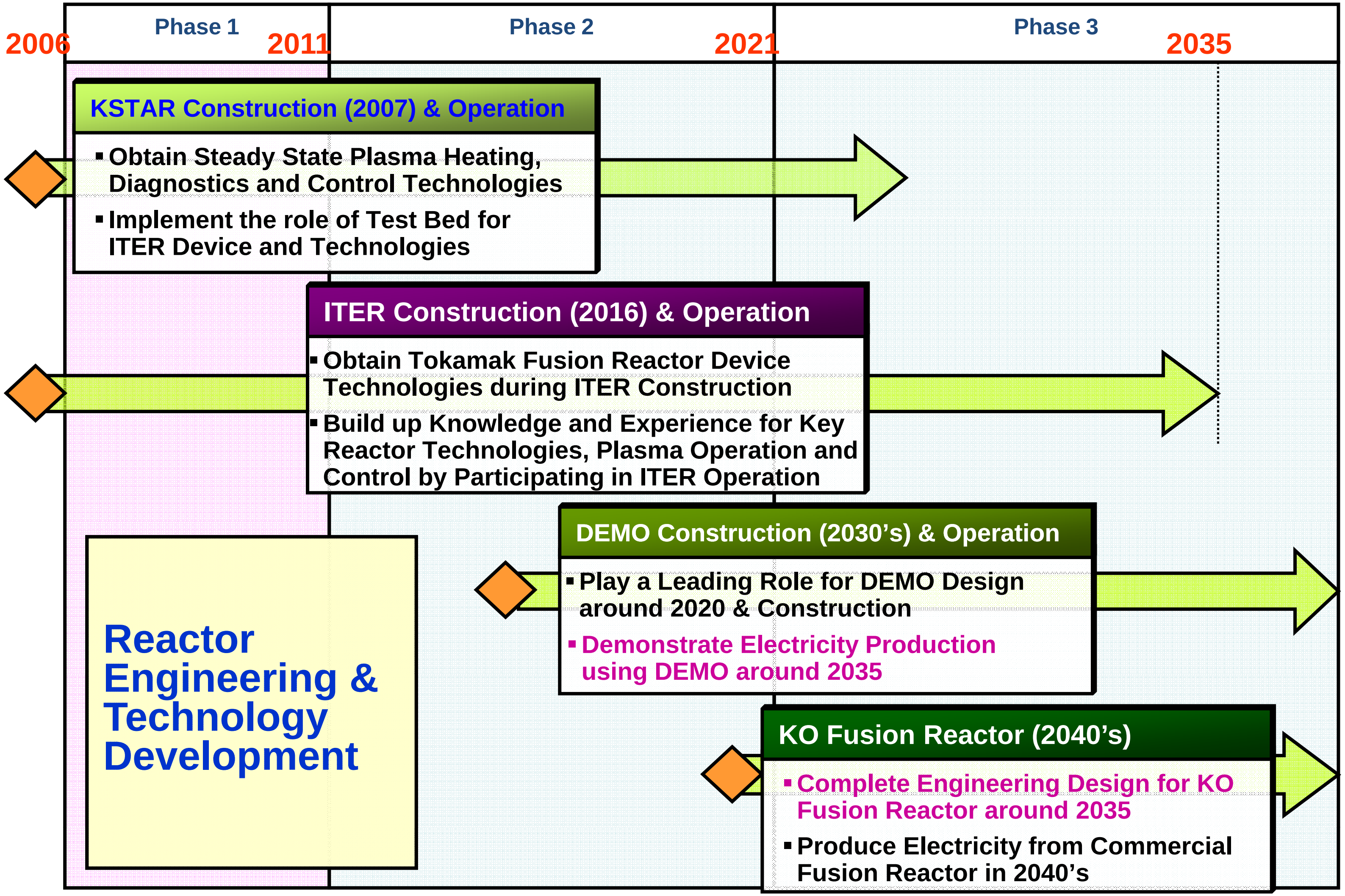
Fusion Energy ?

- Abundant in Fuel (D and T (Transmutation by Lithium))
- No CO_2 gas Emission and No air Pollution
- No High and Long-lived Radioactive Wastes
- Intrinsically Safe: If fuel supply stops, fusion reaction stops

Fusion Energy, an Ideal energy source, but still many Works to be done.

Fusion gives the best future opportunity for Korea to realize Energy dream.
- World experts and specialists can work together (KSTAR & ITER)
- Huge investment for a single country to develop (needs collaboration)

KO Fusion Energy Development Phases



Phase 1

2006

2011

Phase 2

2021

Phase 3

2035

KSTAR Construction (2007) & Operation

- Obtain Steady State Plasma Heating, Diagnostics and Control Technologies
- Implement the role of Test Bed for ITER Device and Technologies

ITER Construction (2016) & Operation

- Obtain Tokamak Fusion Reactor Device Technologies during ITER Construction
- Build up Knowledge and Experience for Key Reactor Technologies, Plasma Operation and Control by Participating in ITER Operation

DEMO Construction (2030's) & Operation

- Play a Leading Role for DEMO Design around 2020 & Construction
- Demonstrate Electricity Production using DEMO around 2035

KO Fusion Reactor (2040's)

- Complete Engineering Design for KO Fusion Reactor around 2035
- Produce Electricity from Commercial Fusion Reactor in 2040's

Reactor Engineering & Technology Development

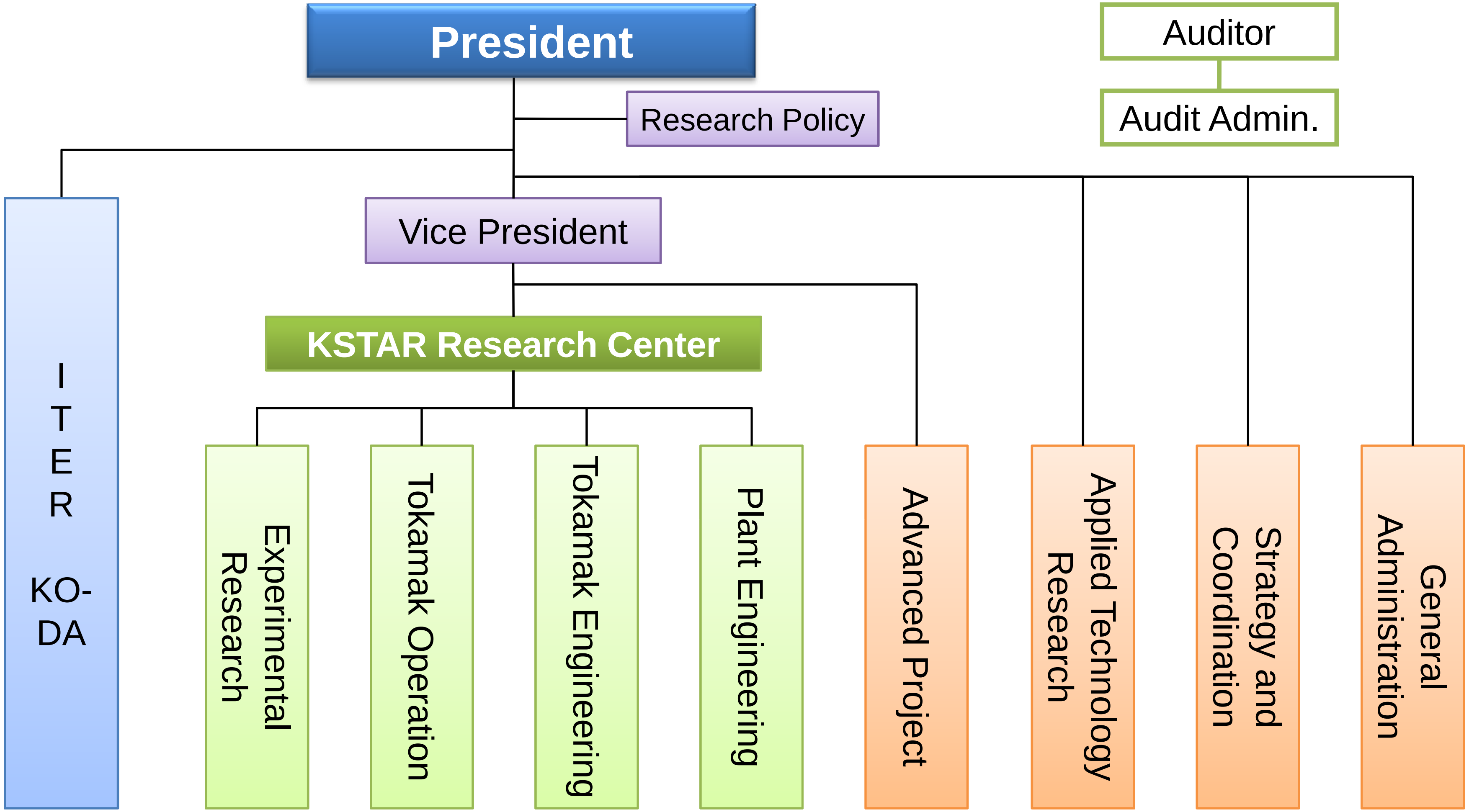
Fusion Energy Development Promotion Act

❖ For establishing a long-term fusion energy strategy and assuring national energy security, the Fusion Energy Development Promotion Act was legislated.

Fusion Energy Development Promotion Act

- Mid-term and Long-term Planning and Resource Allocation
- Establishment of a Central Institute for Self-sustenance of Fusion R&D
- Legal support in taxation and financing and Support for International Collaboration (ITER) and exchange

Organization



President

Research Policy

Auditor

Audit Admin.

Vice President

KSTAR Research Center

ITER KO-DA

Experimental Research

Tokamak Operation

Tokamak Engineering

Plant Engineering

Advanced Project

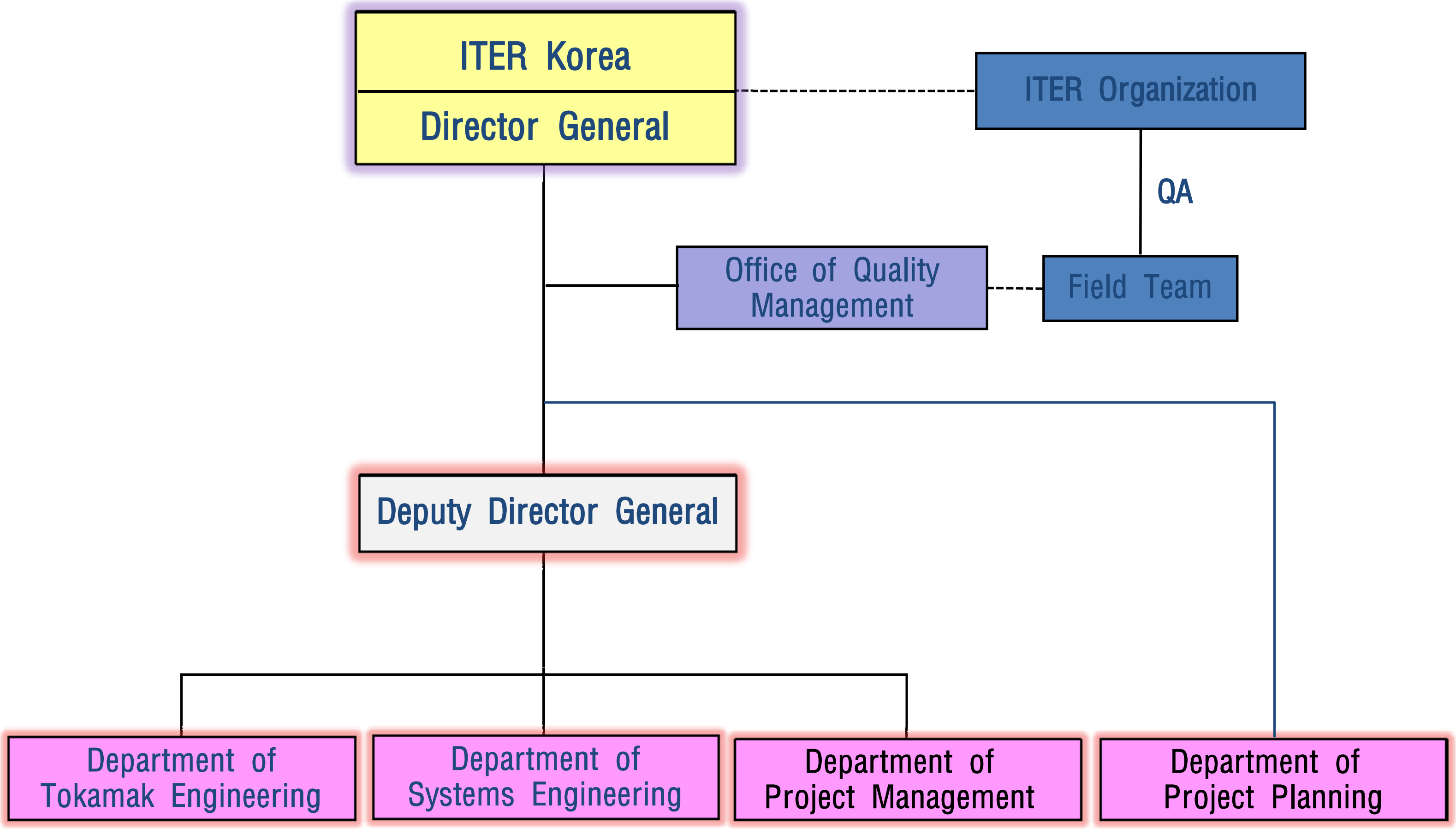
Applied Technology Research

Strategy and Coordination

General Administration

Organization Chart of the KO-DA

(Total Staff: 75)



ITER Korea

Director General

ITER Organization

QA

Office of Quality Management

Field Team

Deputy Director General

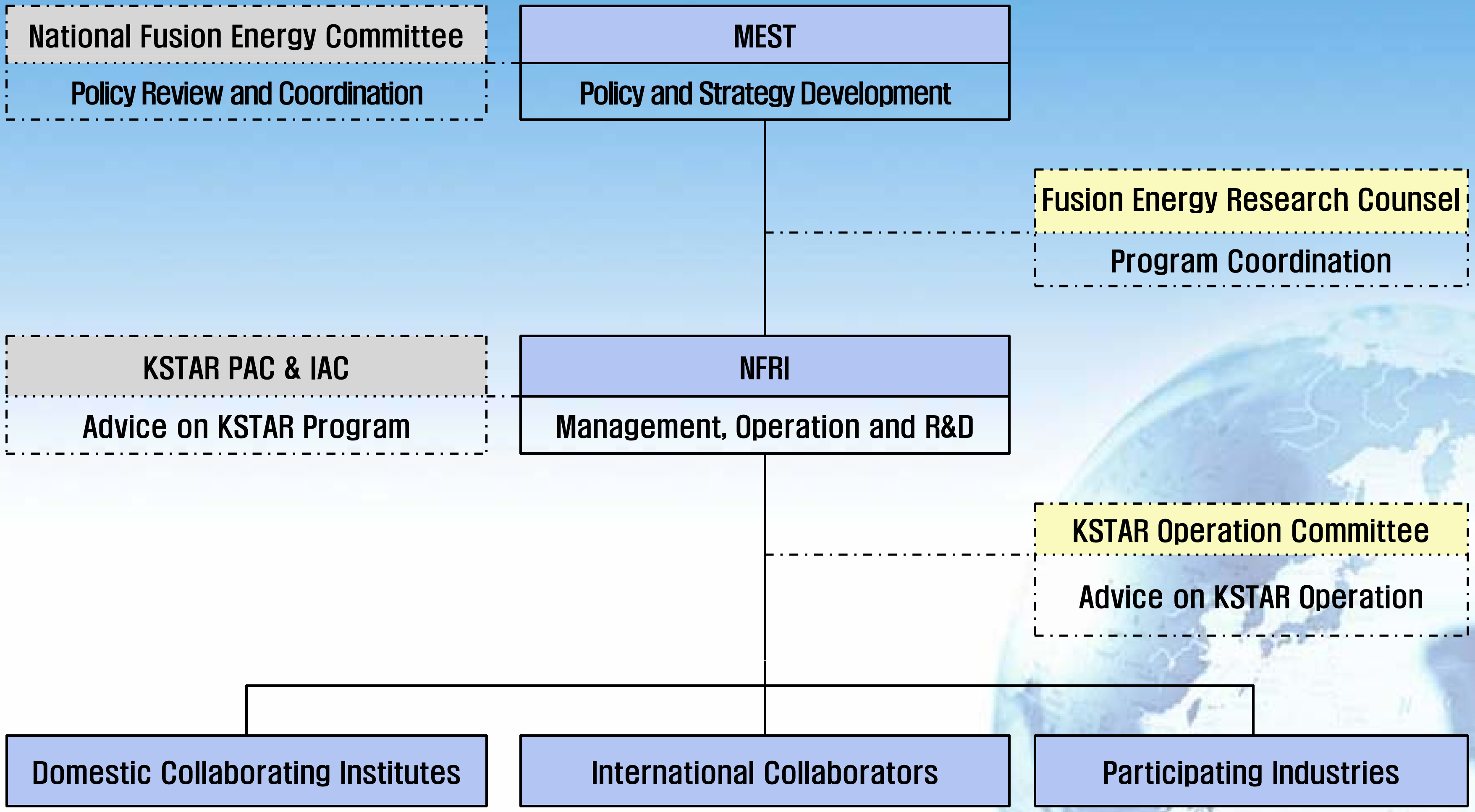
Department of Tokamak Engineering

Department of Systems Engineering

Department of Project Management

Department of Project Planning

Governance for KSTAR



National Fusion Energy Committee

Policy Review and Coordination

MEST

Policy and Strategy Development

Fusion Energy Research Counsel

Program Coordination

KSTAR PAC & IAC

Advice on KSTAR Program

NFRI

Management, Operation and R&D

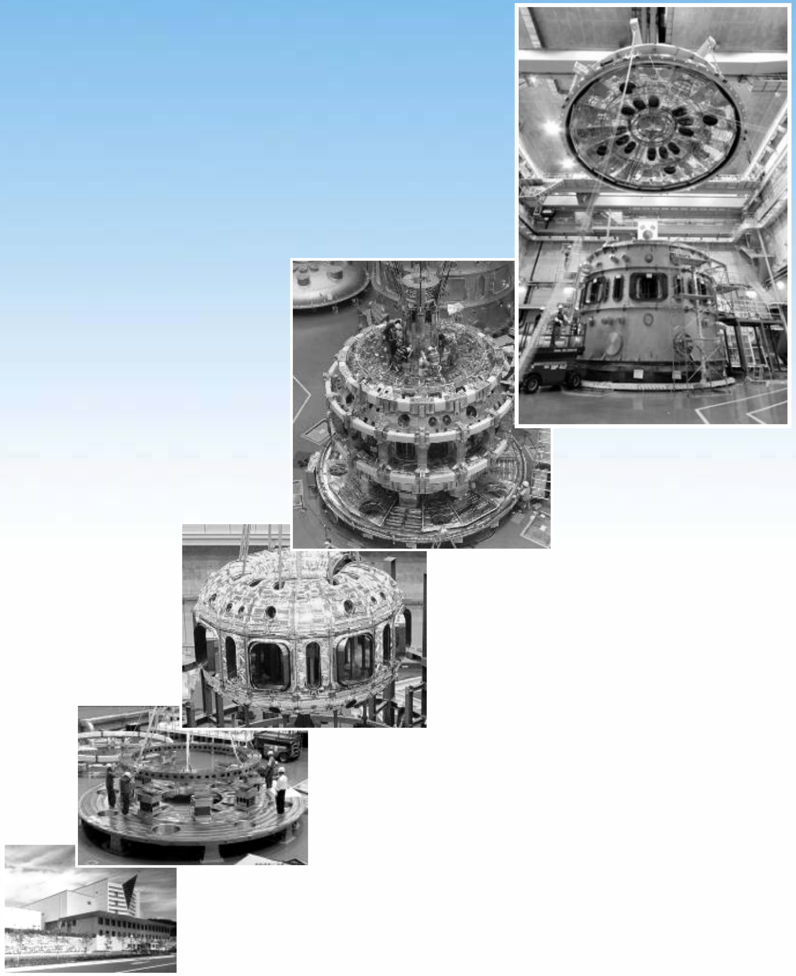
KSTAR Operation Committee

Advice on KSTAR Operation

Domestic Collaborating Institutes

International Collaborators

Participating Industries



2

KSTAR Program

KSTAR Mission & Progress

Mission :

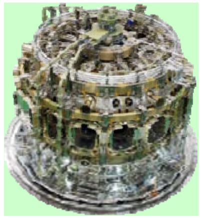
- to develop a steady-state-capable advanced superconducting tokamak
- to establish the scientific and technological base for an attractive fusion reactor as a future energy source

‘95.12 **‘98.8** **‘02.05** **‘07.8** **‘08.6**

KSTAR Project Approval

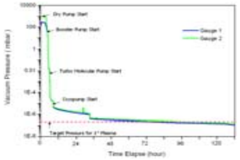
Conceptual Design & Basic R&D

Engineering Design Completed



Machine Construction Completed

First Plasma



Operation

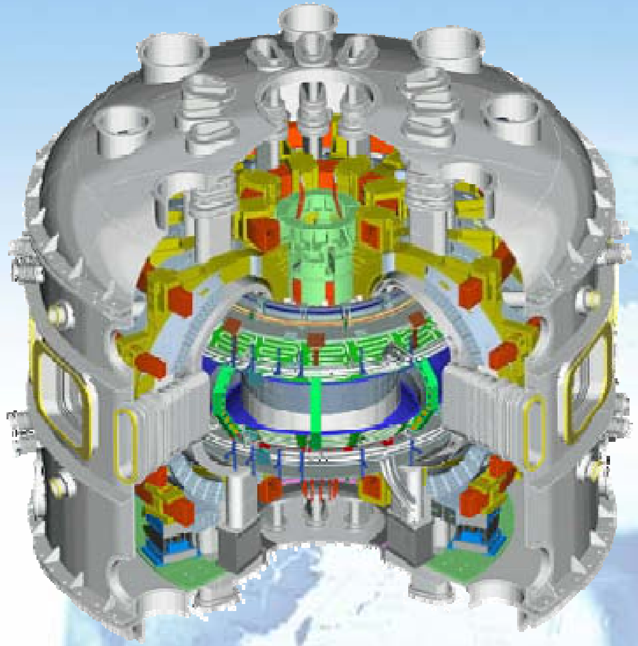
KSTAR Key Features

Key features

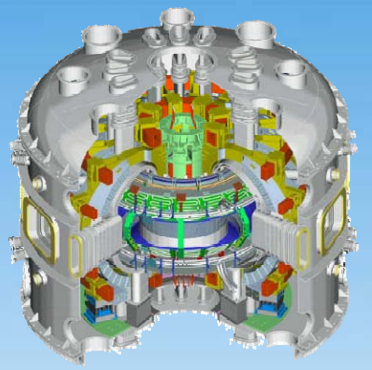
Features

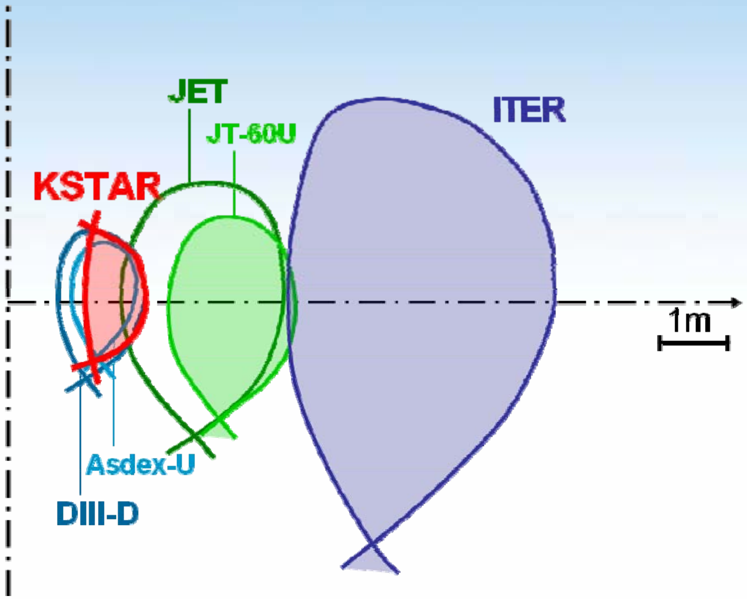
- **High efficient tokamak**
  - middle size & mega-ampere class
- **Steady-state & ITER relevant device**
  - Nb_3Sn superconducting magnet
  - active cooled in-vessel components
  - long-pulse non-inductive heating and current drive
- **High performance operational capability**
  - passive stabilizer
  - in-vessel control coils
  - strong shaping

Schematics of the KSTAR device



KSTAR Parameters

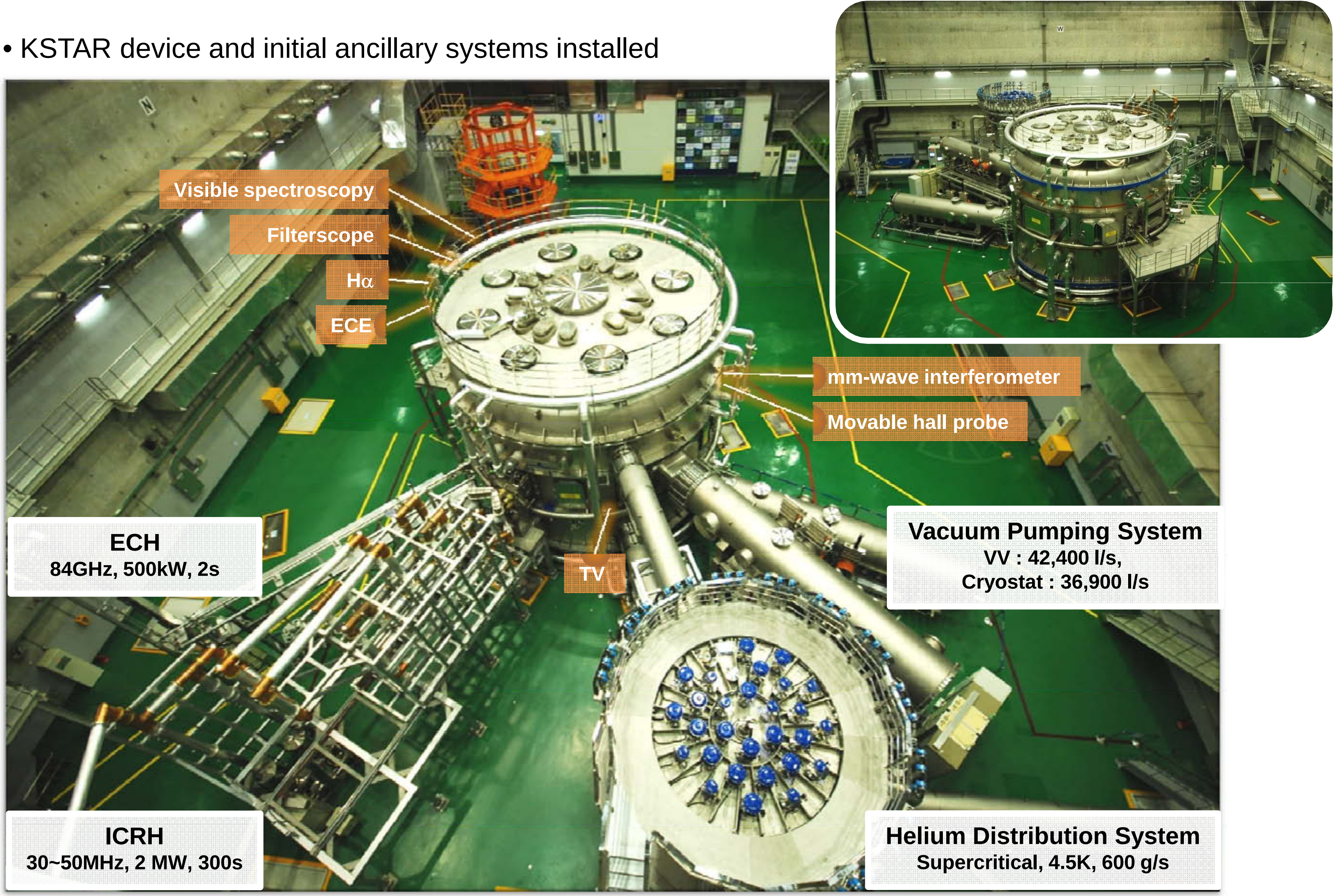




PARAMETERS	KSTAR	ITER
Major radius, R_0	**1.8 m**	**6.2 m**
Minor radius, a	**0.5 m**	**2.0 m**
Elongation, κ	**2.0**	**1.7**
Triangularity, δ	**0.8**	**0.33**
Plasma volume	**17.8 m^3**	**830 m^3**
Plasma surface area	**56 m^2**	**680 m^2**
Plasma cross section	**1.6 m^2**	**22 m^2**
Plasma shape	**DN, SN**	**SN**
Plasma current, I_P	**> 2.0 MA**	**15 (17) MA**
Toroidal field, B_0	**> 3.5 T**	**5.3 T**
Pulse length	**> 300 s**	**400 s**
β_N	**~ 5.0**	**1.8 (2.5)**
Plasma fuel	**H, D-D**	**H, D-T**
Superconductor	**Nb_3Sn, NbTi**	**Nb_3Sn, NbTi**
Auxiliary heating /CD	**~ 28 MW**	**73 (110) MW**
Cryogenic	**9 kW @4.5K**	

KSTAR Tokamak

- KSTAR device and initial ancillary systems installed



ECH
84GHz, 500kW, 2s

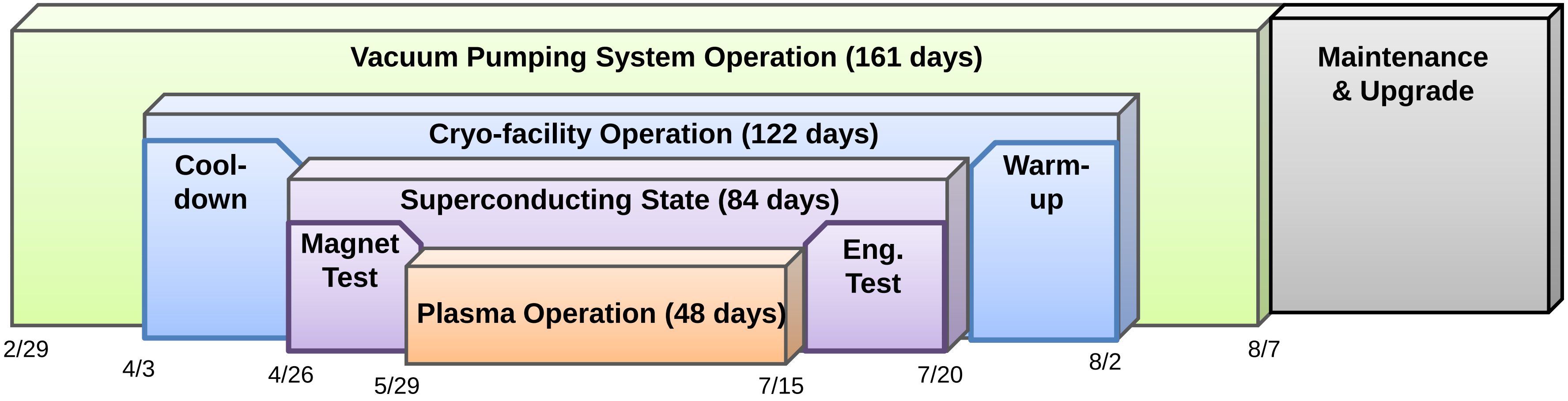
ICRH
30~50MHz, 2 MW, 300s

Vacuum Pumping System
VV : 42,400 l/s,
Cryostat : 36,900 l/s

Helium Distribution System
Supercritical, 4.5K, 600 g/s

Commissioning Progress

- Commissioning Process


Vacuum Pumping System Operation (161 days)

Maintenance & Upgrade

Cryo-facility Operation (122 days)

Cool-down

Warm-up

Superconducting State (84 days)

Magnet Test

Eng. Test

Plasma Operation (48 days)

KEY DATES	COMMISSIONING PROGRESS
Sep. 14, 2007	Tokamak construction completed
Feb. 29, 2008	Vacuum pumping started after final inspection
Apr. 03, 2008	Magnet system cool-down started (9 kW refrigerator)
Apr. 23, 2008	SC phase transition detected (TF coil at 18 K)
Apr. 26, 2008	Cool-down completed (5 K, SHe 600 g/s)
May 05, 2008	Joint resistance & coil insulation measured
May 12, 2008	TF coil commissioning completed (15 kA, 8 hr)
May 27, 2008	PF coil commissioning completed (4 kA)
May 29, 2008	ECH pre-ionization test started (1.5 T, 84GHz)
Jun. 13, 2008	First plasma achieved (107 kA, ECH assisted)
Jul. 15, 2008	1st plasma campaign completed (pulse length over 800 ms)
Jul. 20, 2008	Warm up started

Operation & Research Goal

- High performance plasma research :

- High beta plasma operation and control especially effective heating system operation

- NTM suppression using ECCD
- RWM control using IVCC coil
- ELM stabilization using IVCC coil

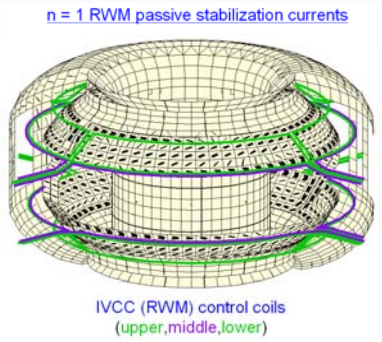
- Slow plasma ramp-up assisted by additional heating system

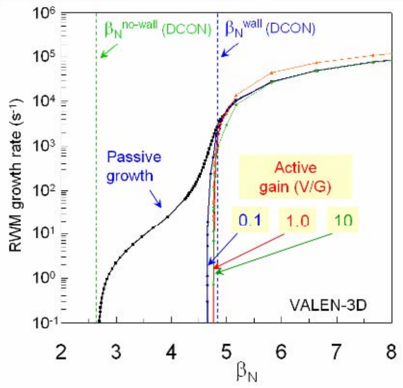
- Steady-state operation research :

- High non-inductive current drive and high bootstrap current generation

- Long pulse heating system development
- High temperature PFC components
- Various disruption mitigation

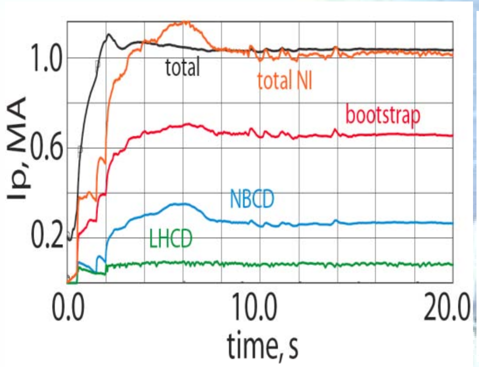
- Embedded real-time measurement and control for long pulse plasma
- Innovative diagnostics

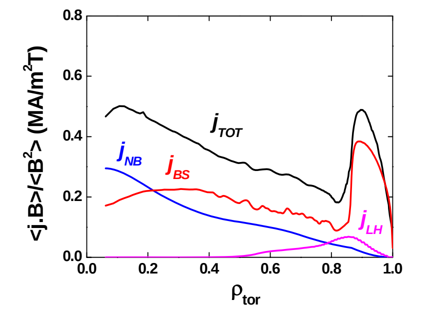




Ref. S. Sabbagh, "stabilization of KSTAR high beta equilibria" (2007)

High beta stabilization by IVCC





Non-inductive CD scenario

ITER relevant Operation & Research

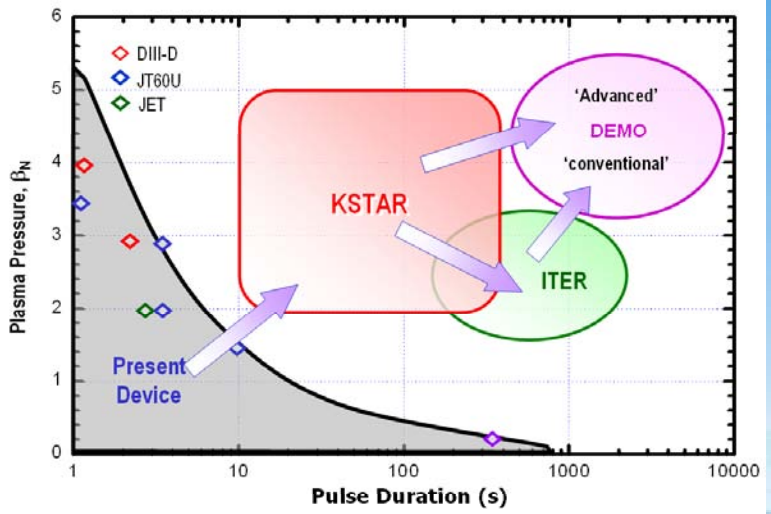
- KSTAR will be one of the most effective devices for ITER relevant and for an attractive fusion reactor physics operation.

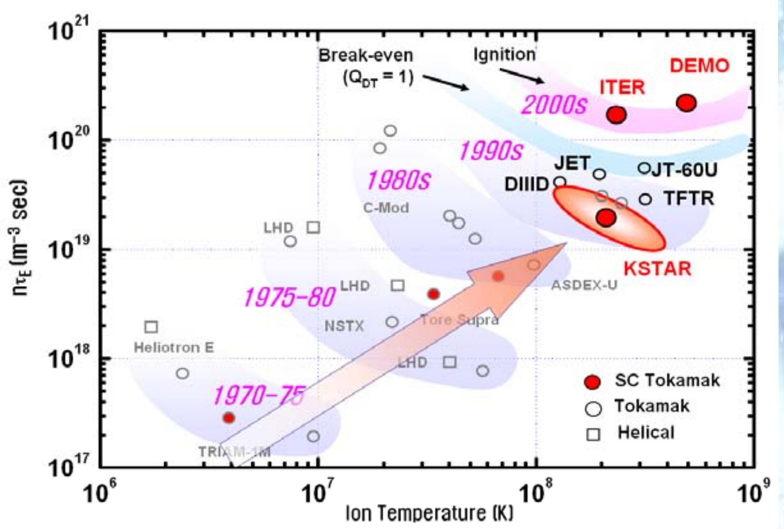
- ITER operational scenario test
- Long pulse operation (~ 300 s)
- Simulation for ITER AT operation scenario

- Superconducting coil characteristics for high performance plasma operation
- Mechanical performance of the structures under high magnetic forces

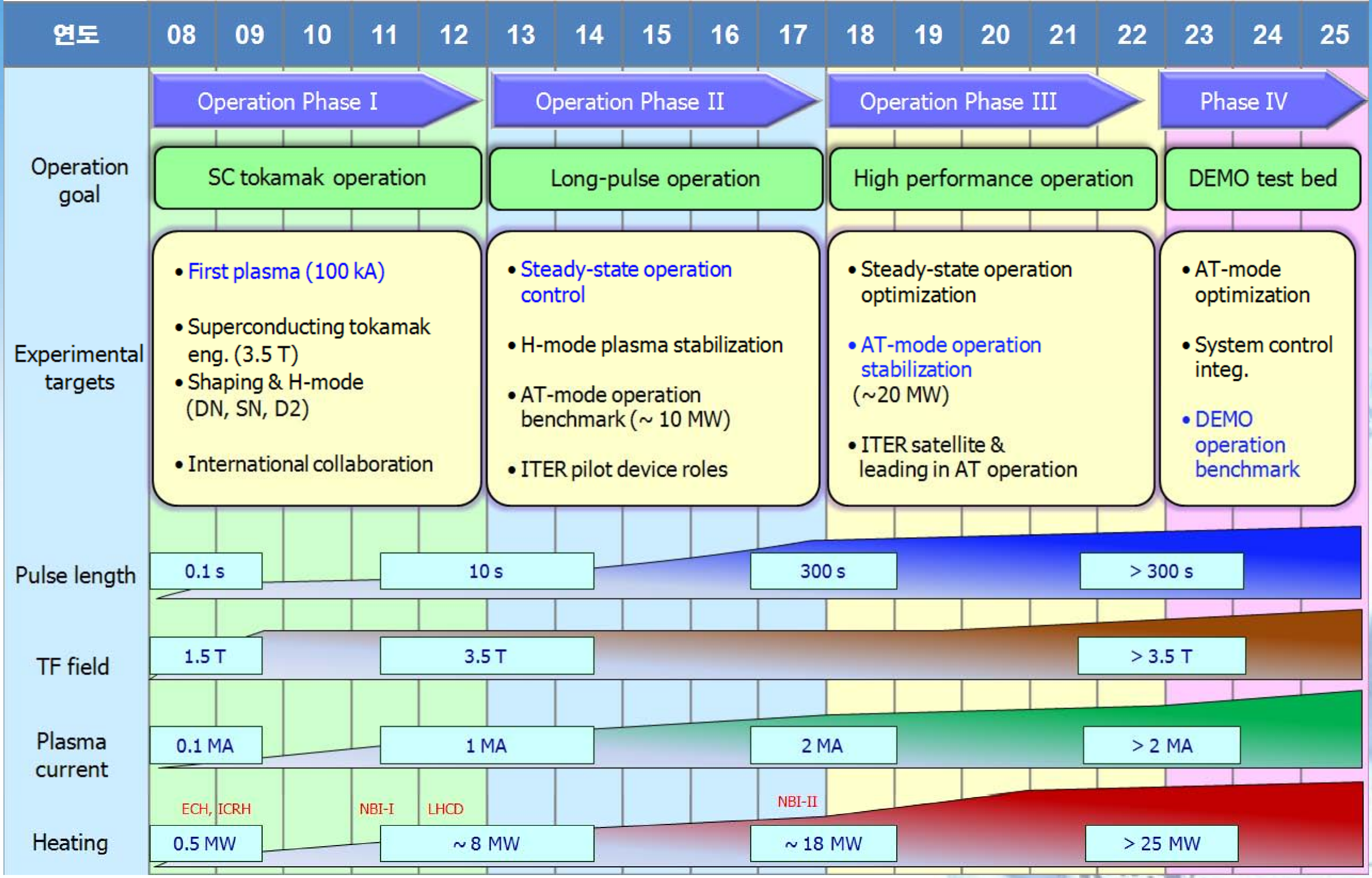
- Long-pulse plasma control
- Power supply control (SC magnet & IVCC)

- Divertor material test at high temperature
- ITER TBM material test





KSTAR operation & experimental plan



연도	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Operation Phase I					Operation Phase II					Operation Phase III					Phase IV		
Operation goal	SC tokamak operation					Long-pulse operation					High performance operation					DEMO test bed		
Experimental targets	• First plasma (100 kA) • Superconducting tokamak eng. (3.5 T) • Shaping & H-mode (DN, SN, D2) • International collaboration					• Steady-state operation control • H-mode plasma stabilization • AT-mode operation benchmark (~ 10 MW) • ITER pilot device roles					• Steady-state operation optimization • AT-mode operation stabilization (~20 MW) • ITER satellite & leading in AT operation					• AT-mode optimization • System control integ. • DEMO operation benchmark		
Pulse length	0.1 s			10 s						300 s				> 300 s				
TF field	1.5 T			3.5 T										> 3.5 T				
Plasma current	0.1 MA			1 MA						2 MA				> 2 MA				
Heating	ECH,	ICRH		NBI-I	LHCD					NBI-II								
	0.5 MW			~ 8 MW						~ 18 MW				> 25 MW				

Near-term KSTAR Operation & Upgrade Plan

Last updated : Jan. 8, 2009

	FY 08	FY 09	FY 10	FY 11	FY 12
Operation (+CD & WU)	**08. 4 ~ 08. 7 (4 mon.)**	**09. 9 ~ 09.12 (4 mon.)**	**10.6 ~ 10. 10 (5 mon.)**	**11. 3~ 11. 7 (5 mon.)**	**12. 3 ~ 08. 7 (5 mon.)**
Experimental Goals	• First plasma startup • 2nd Harmonic ECH pre-ionization	• 1st Harmonic ECH Pre-ionization • Startup stabilization	• Shaping control & vertical stabilization • Heating	• Confinement (L-H) • Stabilization • Heating	• Plasma–Wall Interaction • Profile control • RWM, ELM control • Off-axis current drive
Operation Parameters	• B_T ~ 1.5 T • I_P > 0.1 MA • t_P > 0.1 s • Te > 0.3 keV • Ti ~ 0 keV • Flux ~ 1 Wb • Shape ~ Circular • Gas : H_2	• B_T ~ 3 T • I_P > 0.3 MA • t_P > 2 s • Te > 0.3 keV • Ti ~ 0.3 keV • Flux ~ 2 Wb • Shape ~ Circular • Gas : H_2, D_2	• B_T ~ 3 T • I_P ~ 1 MA • t_P ~ 10 s • Te ~ 1 keV • Ti ~ 1 keV • Flux ~ 4 Wb • Shape ~ DN(double null) • Gas : H_2, D_2	• B_T ~ 3 T • I_P ~ 1.5 MA • t_P ~ 10 s • Te ~ 1 keV • Ti ~ 3 keV • Flux ~ 6 Wb • Shape ~ DN & SN • Gas : D_2	• B_T ~ 3 T • I_P ~ 2 MA (10 s) • t_P > 100 s (0.5 MA) • Te ~ 1 keV • Ti ~ 5 keV • Flux ~ 8 Wb • Shape ~ DN & SN • Gas : D_2
PFC & conditioning	• Inboard limiter (belt) • Gas puff	• Inboard limiter (w/o cooling) • Boronization	• Divertor / Passive plate • PFC baking • In-vessel coil	• Cryopump operation • PFC cooling	• PFC cooling • *Pellet*
Magnetic control	• TF : 1.5 T • PF : 4 kA unipolar	• TF : up to 3.5 T • PF : +/-4 kA	• TF : up to 3.5 T • PF : +/-10 kA • IVCC : VS, RS	• TF : up to 3.5 T • PF : +/-15 kA • IVCC : FEC. RMP	• TF : up to 3.5 T • PF : +/-20 kA • IVCC : RMP, RWM
Heating operation	• ECH(84G): 0.5MW, 0.4s	• ECH(84G): 0.5MW, 2s • ICRH(45M): 0.3MW, 10 s	• ECH(84G): 0.5MW, 2s • ICRH(45M): 1MW, 10 s • NBI: 1.0MW, 10s • LHCD: 0.5MW, 2s	• ECH(84G): 0.5MW, 2s • ICRH(45M): 2MW, 10 s • NBI: 2.5MW, 10s • LHCD: 0.5MW, 2s • ECCD(170G): 1MW, 10s	• ECH(84G): 0.5MW, 2s • ICRH(45M): 2MW, 300 s • NBI :5MW, 300s • LHCD : 1MW, 2s • ECCD(170G): 1MW, 300s
Diagnostics	• MD (77 Ch)/ MMWI / ECE / Hα / filterscope / VS / TV	• MD/ MMWI / ECE / Hα / filterscope / VS / TV • PD / XCS (1 set) / Bolometer (resistive) / Reflect. / Soft X-ray	• MD / MMWI / ECE / Hα / filterscope / VS / TV • PD / XCS / Bolometer / Reflect. / Soft X-ray • Thomson Spectroscopy / Hard X-ray / Fast neutral / IR TV / ECEI	• MD / MMWI / ECE / Hα / filterscope / VS / TV • PD / XCS / Bolometer / Reflect. / Soft X-ray • TS / Hard X-ray / Fast neutral / IR TV / ECEI • MSE / FIR / CES / neutron	

Upgrade targeting a Shaped H-mode

- For 1st campaign, the target plasma was Ip=100kA, τ_{pulse}=100ms, B_T=1.5T, focusing on checking the machine reliability and the hardware integration
- Our two-year goal is to get a diverted H-mode by 2010

Upgrade for 2nd campaign (Sep. 2009)

Circular, B_T=3.5T, Ip~0.5 MA
Pulse length~10s
ICRH+ECH heated L-mode
Partially covered PFCs

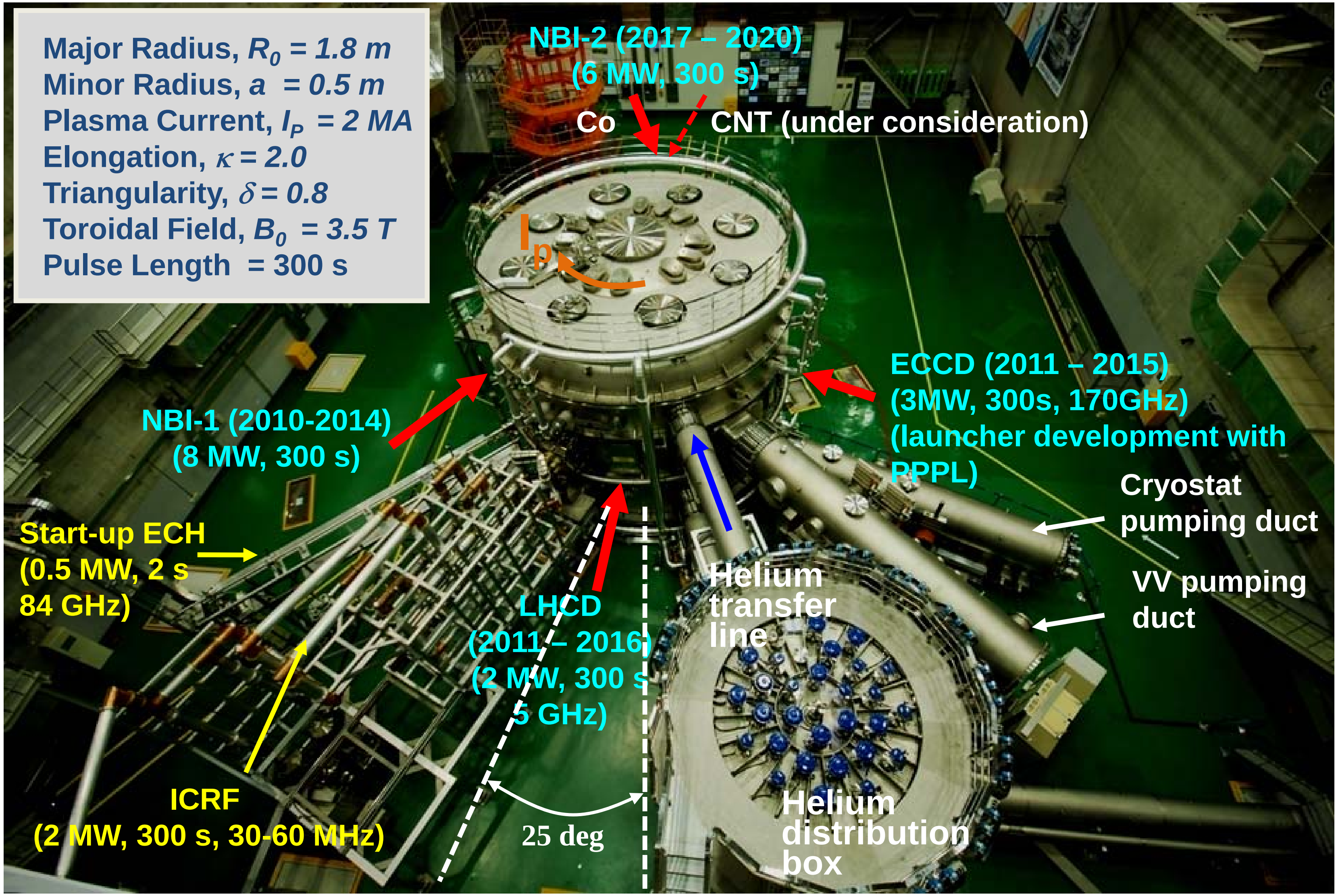
Upgrade for 3rd campaign (Jun. 2010)

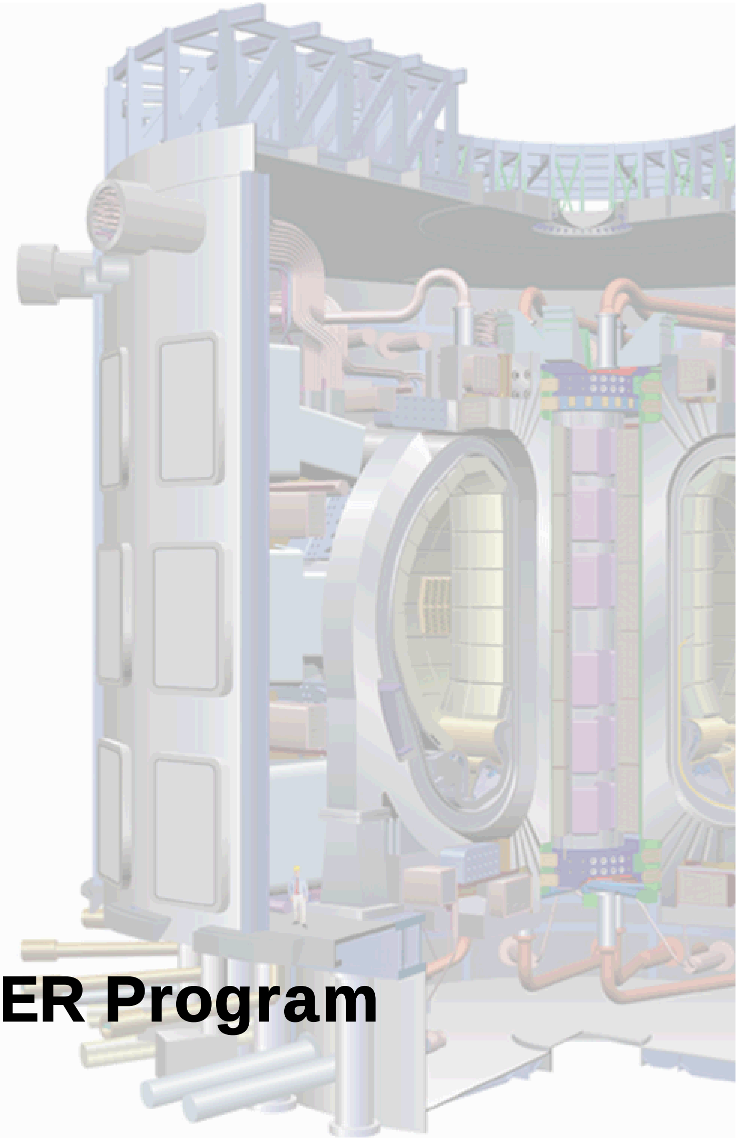
Shaped H-mode(B_T=2T, Ip~1 MA)
D-shaped double-null(κ=2.0, δ=0.8)
Full CFC+graphite PFCs
P_{NBI}~1.5MW, P_{ICRH}~2MW, P_{LHCD}~0.5MW
In-vessel coils

After 2010, we are targeting long-pulse advanced tokamak research by 2012.

KSTAR & heating devices

Major Radius, $R_0 = 1.8\ m$
Minor Radius, $a = 0.5\ m$
Plasma Current, $I_P = 2\ MA$
Elongation, $\kappa = 2.0$
Triangularity, $\delta = 0.8$
Toroidal Field, $B_0 = 3.5\ T$
Pulse Length = 300 s





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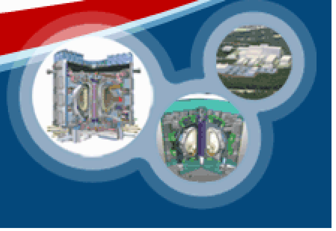
ITER Program



ITER Staff by Member Status: March 2009

Professional Staff by Member Countries

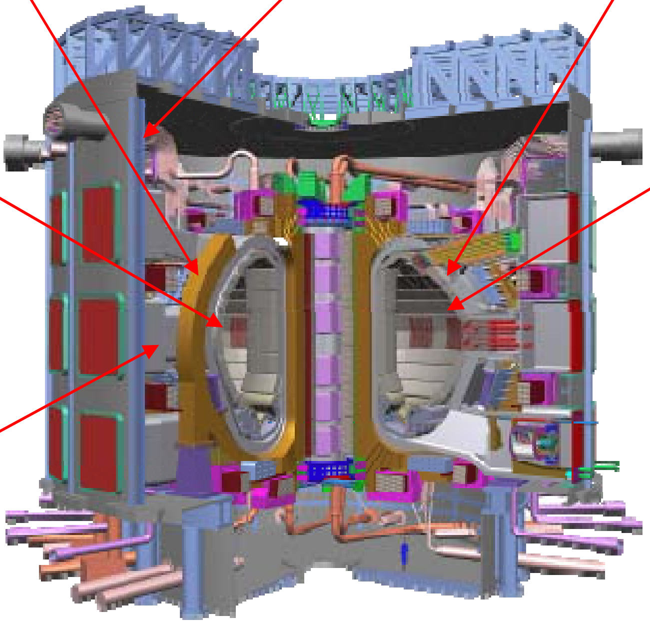
Party	EU	KO	IN	JA	CN	RF	US	Total
No.	141	15	10	19	15	18	17	235

- Total of 22 nationalities
- Support Staff : 86

KO Professional Staff

Department	Safety and Security	Tokamak	Project Office	Central Engineering & Plant Support	Total
No.	2	6	3	4	15

KO-DA In-kind Contribution to ITER



1. TF Conductor
Total Value (kIUA) : 215.0
KO Allocation : 20.18%
KO Contribution (kIUA) : 43.39

7. Thermal Shield
Total Value (kIUA) : 28.8
KO Allocation : 100%
KO Contribution (kIUA) : 28.8

4. Blanket First Wall
Total Value (kIUA) : 87.0
KO Allocation : 10.5%
KO Contribution (kIUA) : 9.13

2. Vacuum Vessel Main Body
Total Value (kIUA) : 124.2
KO Allocation : 20%
KO Contribution (kIUA) : 24.84

5. Blanket Shield Block
Total Value (kIUA) : 58.0
KO Allocation : 10.5%
KO Contribution (kIUA) : 6.09

3. Vacuum Vessel Port
Total Value (kIUA) : 78.5
KO Allocation : 73.5%
KO Contribution (kIUA) : 57.70

6. Assembly Tooling
Total Value (kIUA) : 22.0
KO Allocation : 100%
KO Contribution (kIUA) : 22.0

8. Tritium SDS
Total Value (kIUA) : 14.5
KO Allocation : 88%
KO Contribution (kIUA) : 12.76

9. AC/DC Converters
Total Value (kIUA) : 82.2
KO Allocation : 38%
KO Contribution (kIUA) : 31.24

10. Diagnostics
Total Value (kIUA) : 137.5
KO Allocation : 3.3%
KO Contribution (kIUA) : 4.54

🟩 Lead Items
🟨 Tokamak Main
🟪 Ancillary

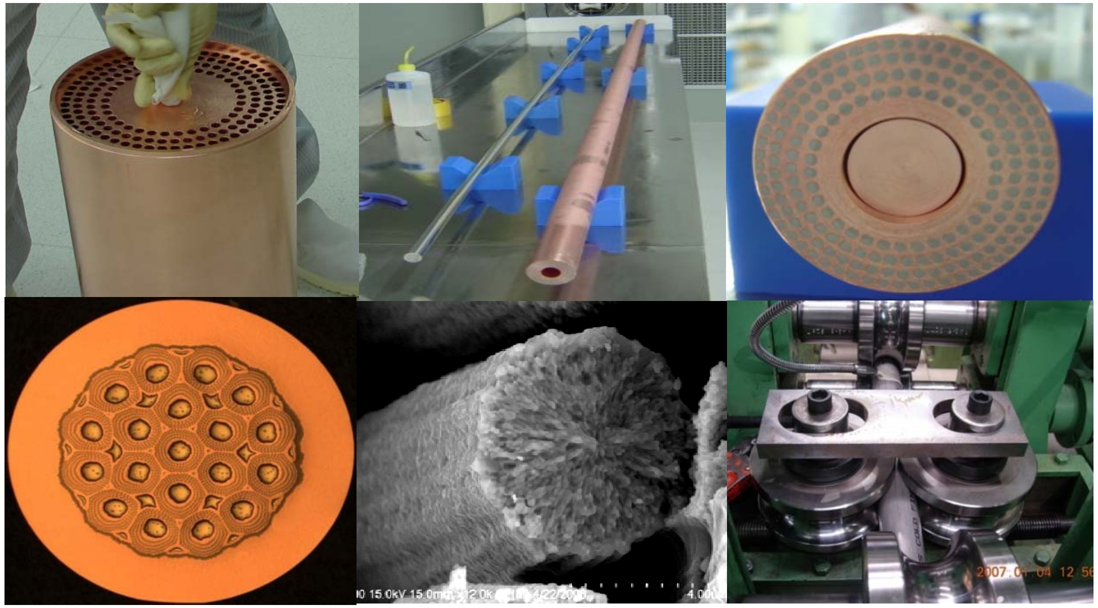
TF Conductor

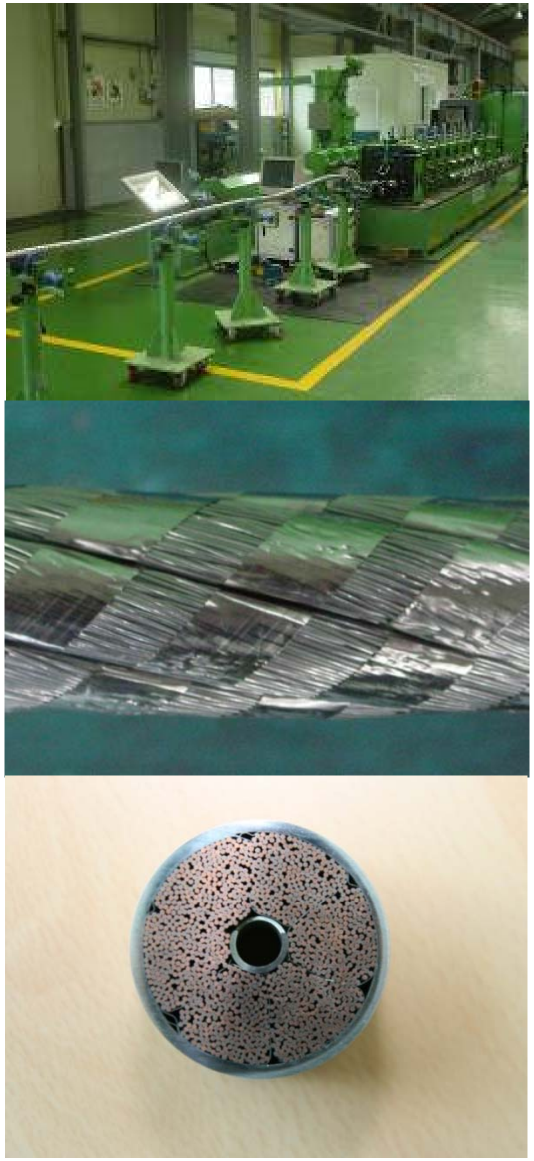
Objectives

- Supply of 20 % of TF conductor to ITER (Lead Items)
  - * 19 of 760m and 8 of 415m TF Conductors

Current works

- Procurement Arrangement signed between KO-DA and ITER Organization on 7th May 2008
- The contract was awarded to KAT & Nexans





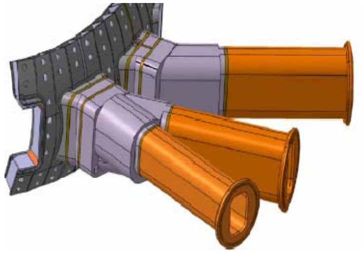
Vacuum Vessel (Main and Ports)

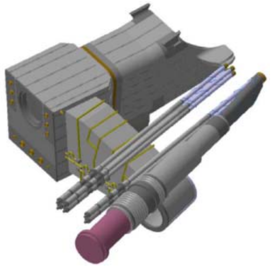
Objectives

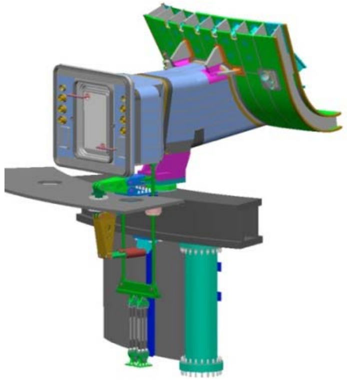
- 20 % of VV main body and 73.5 % of VV ports contribution to ITER (Lead Items)
  * 2 Sectors Main Body, 14 Sets of Equatorial and 9 Sets of Lower Ports
  * 3 Sets of HNB, H/DNB Ports and 9 Sets of VV Supports

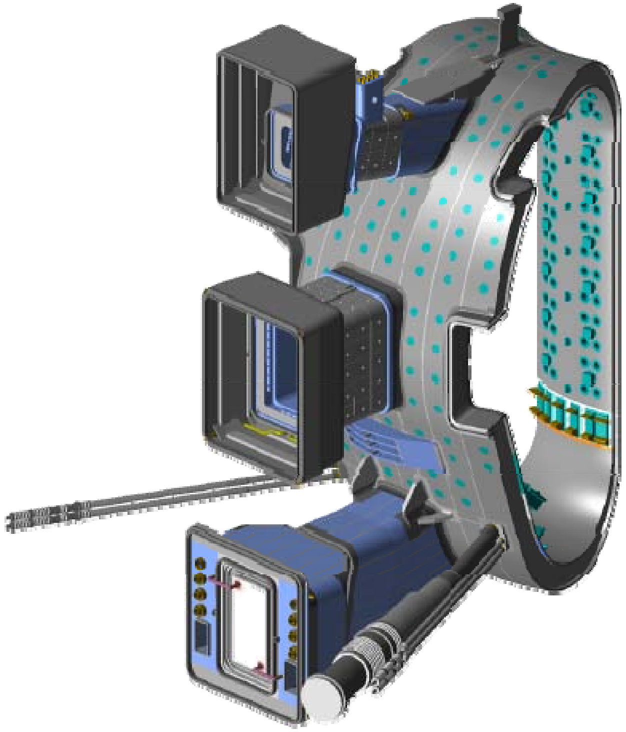
Current works

- Doing detail design (VV Support, NB Liner)
- Developing the fabrication method
- Studying fabrication and assembly tolerances
- Preparation of Call For Tender (CFT)









[VV Sector & Port]

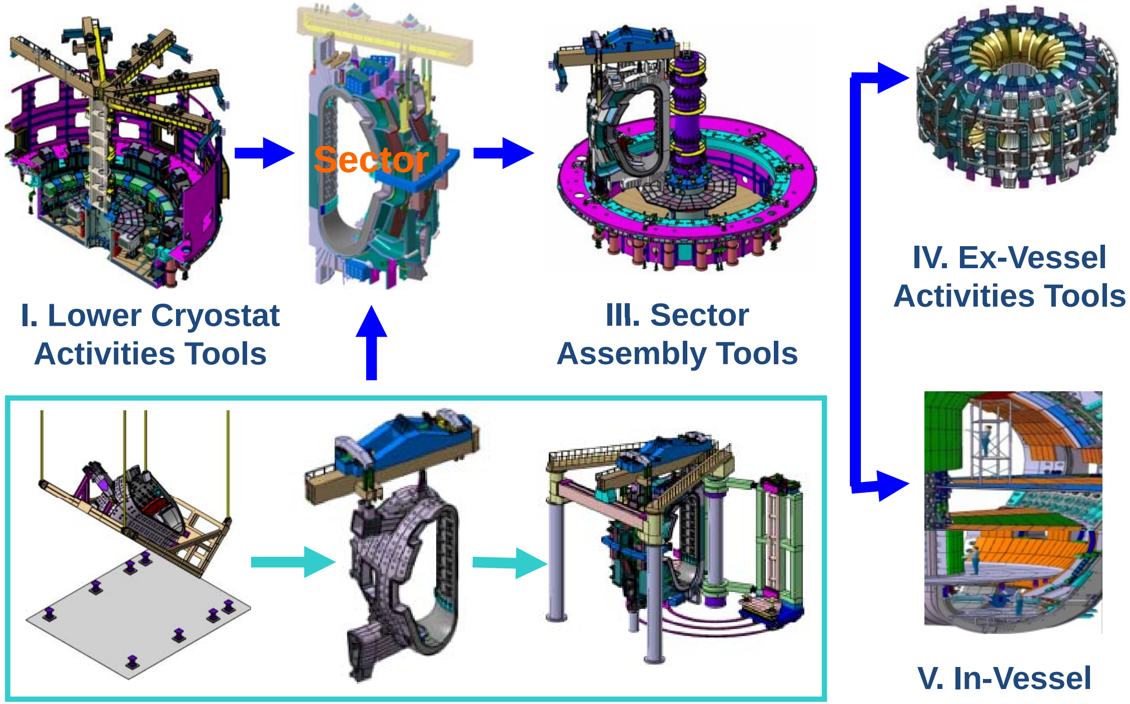
Assembly Tooling

Objectives

- Purpose-built assembly tools contribution to ITER : 100%
  - * About 70 kinds of tools to assemble the ITER Tokamak which includes the cryostat and the components contained therein.

Current works

- Detailed design of assembly tools
  - Lower Cryostat Activities Tools
  - Sector Sub-Assembly Tools
  - Sector Assembly Tools
  - Ex-Vessel Activities Tools
  - In-Vessel Activities Tools
- Structural analysis of assembly tools
- Preparation of technical specification document for PA



I. Lower Cryostat Activities Tools

II. Sector Sub-Assembly Tools

III. Sector Assembly Tools

IV. Ex-Vessel Activities Tools

V. In-Vessel Activities Tools

CODAC (non-procurement, but R&D items)

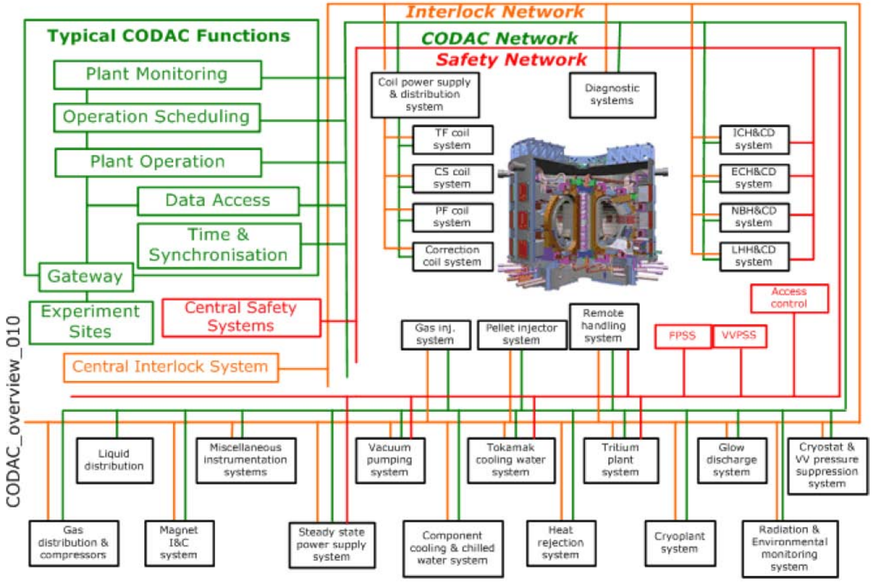
CODAC (Control, Data Access and Communication)

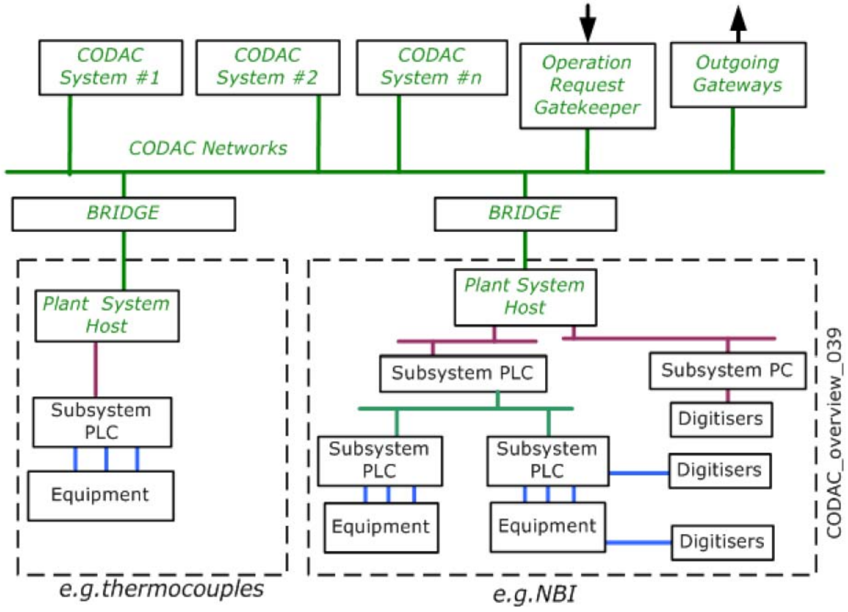
Objectives:

- Participate in the development of ITER integrated control system (CODAC)
- Participate in the open competition for CODAC procurement in the future

Current works

- International cooperation through PMWG activity
- Feasibility study of using EPICS for CODAC middleware (Task Agreement)





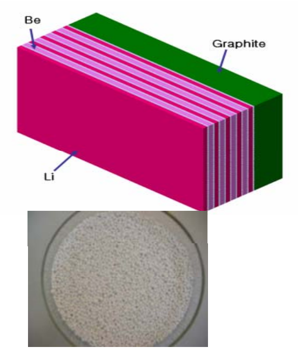
TBM (non-procurement, but R&D items)

Objectives

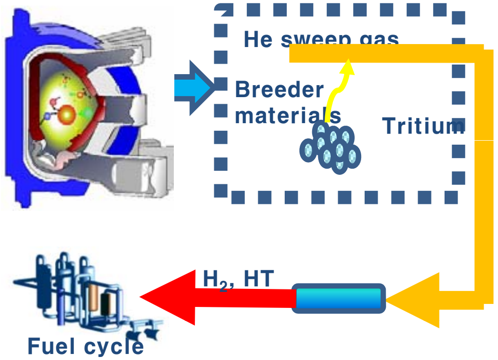
- Development of Korean concept of TBM for future DEMO and NFPP

Current works

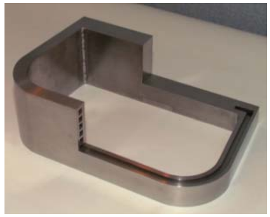
- Conceptual design of KO-TBM (Solid, Liquid)
- Leadership among parties for ITER TBM
- TBM R&D activities
  - Breeder/Multiplier/Reflector Materials
  - Tritium Extraction technology
  - Fabrication technology
  - Measurement system



Material Development

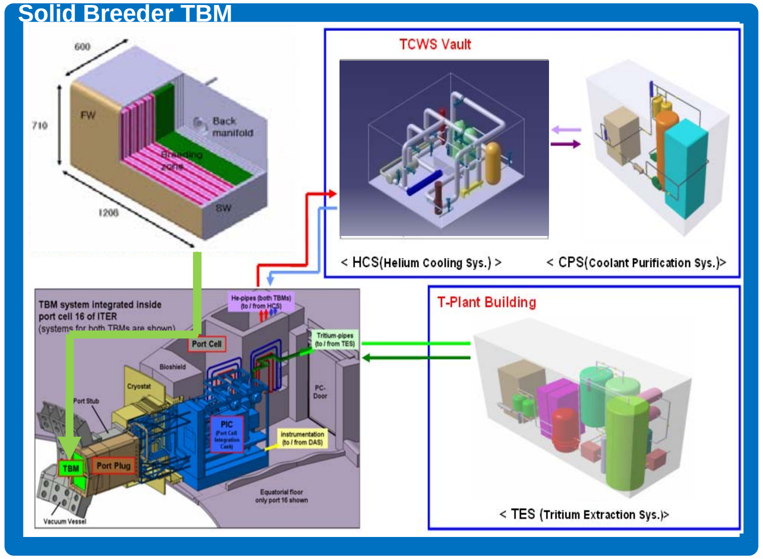


Tritium Extraction technology

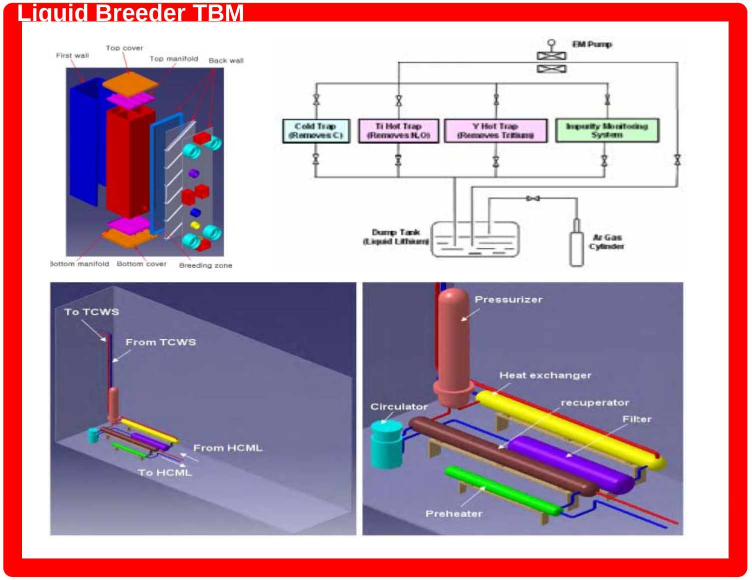


Fabrication technology

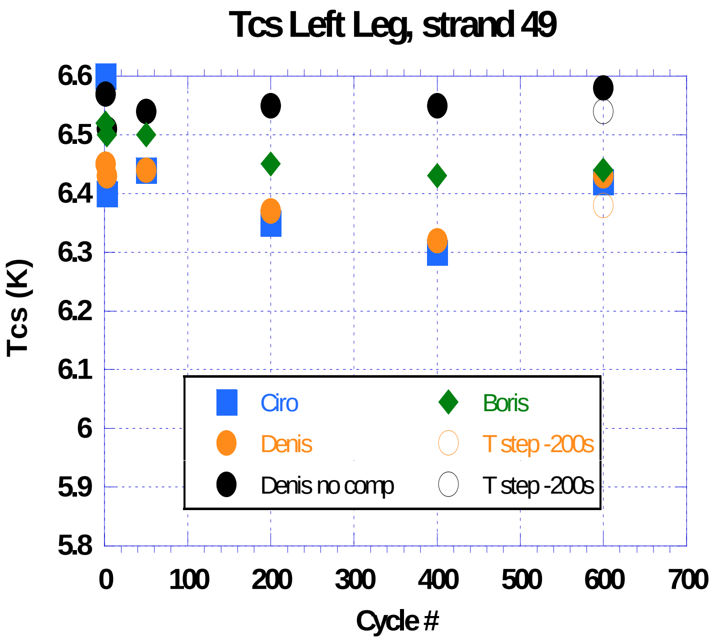
Solid Breeder TBM



Liquid Breeder TBM



Performance Qualification Test (5 Nov. 2008)



Current Sharing Temperature

Tcs = 6.3 ~ 6.6 K > 5.7 K

Successful Performance Qualification Test based on a full size Conductor Performance Qualification Sample (CPQS)

4 Collaboration

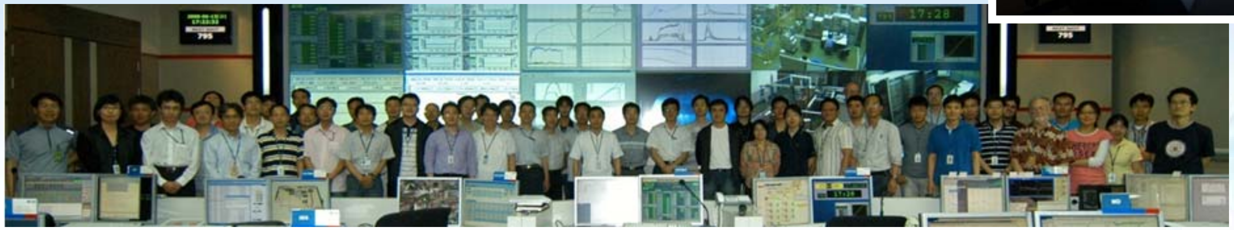
KSTAR as a Collaboratory

User groups and foreign scientists participated in the first campaign

- **Improved clarity and accessibility helps building a collaborative environment**
  Experts from more than ten domestic institutes attended in the major process to make the 1st plasmas.

- **Twenty-seven foreign scientists visited KSTAR during the first campaign**

Domestic experts assessing the preparation process of the 1st plasmas



Foreign scientists participated in the various states during the 1st campaign from US (GA, PPPL), Japan (NIFS, JAEA), Russia (KI), EU (CEA), ITER-IO

Collaboration Strategy

Domestic University Collaboration Network

- Fostering world-class research groups
- Maximizing the connectivity to KSTAR and ITER projects
- Focusing on the basic and creative researches in fusion science

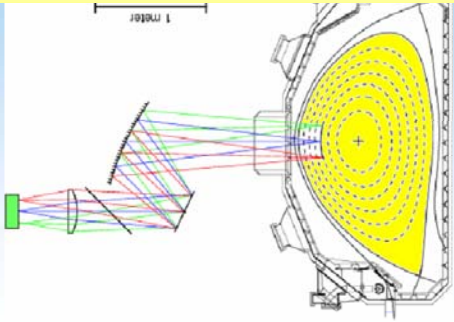
International Collaboration Network

- Collaboration through KSTAR program
- Collaboration with ITER partners
- Collaboration for fusion nuclear technology
- Collaboration with non-ITER partners

Core Universities

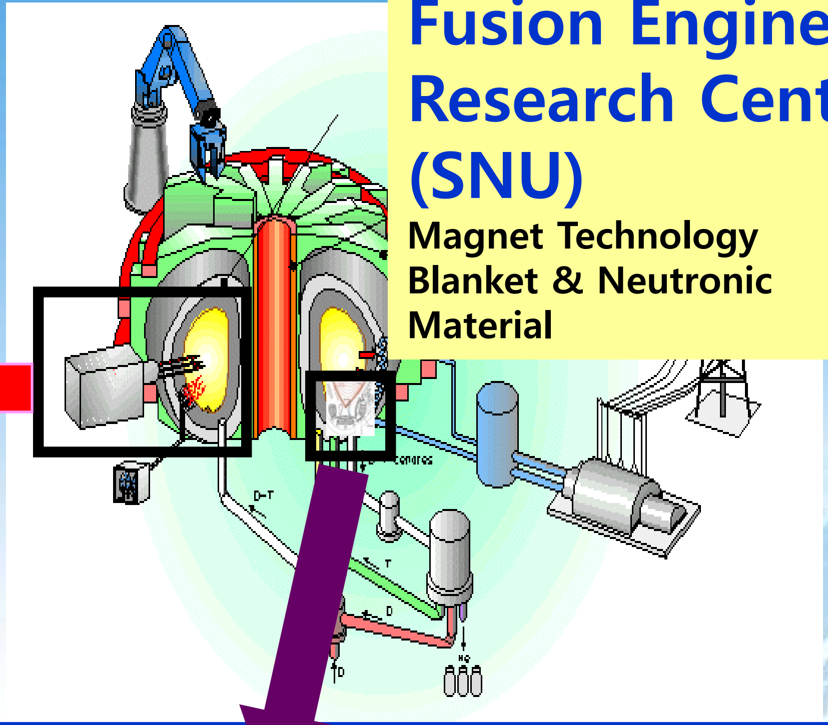
Plasma Core Research Center

Diagnostics
Control
Heating & CD

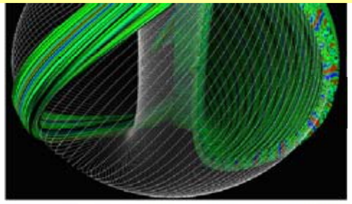


Fusion Engineering Research Center (SNU)

Magnet Technology
Blanket & Neutronic
Material



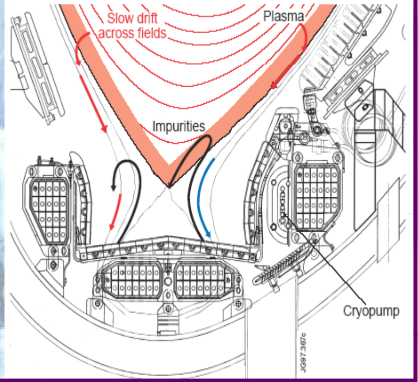
Fusion Simulation Center



Transport
MHD

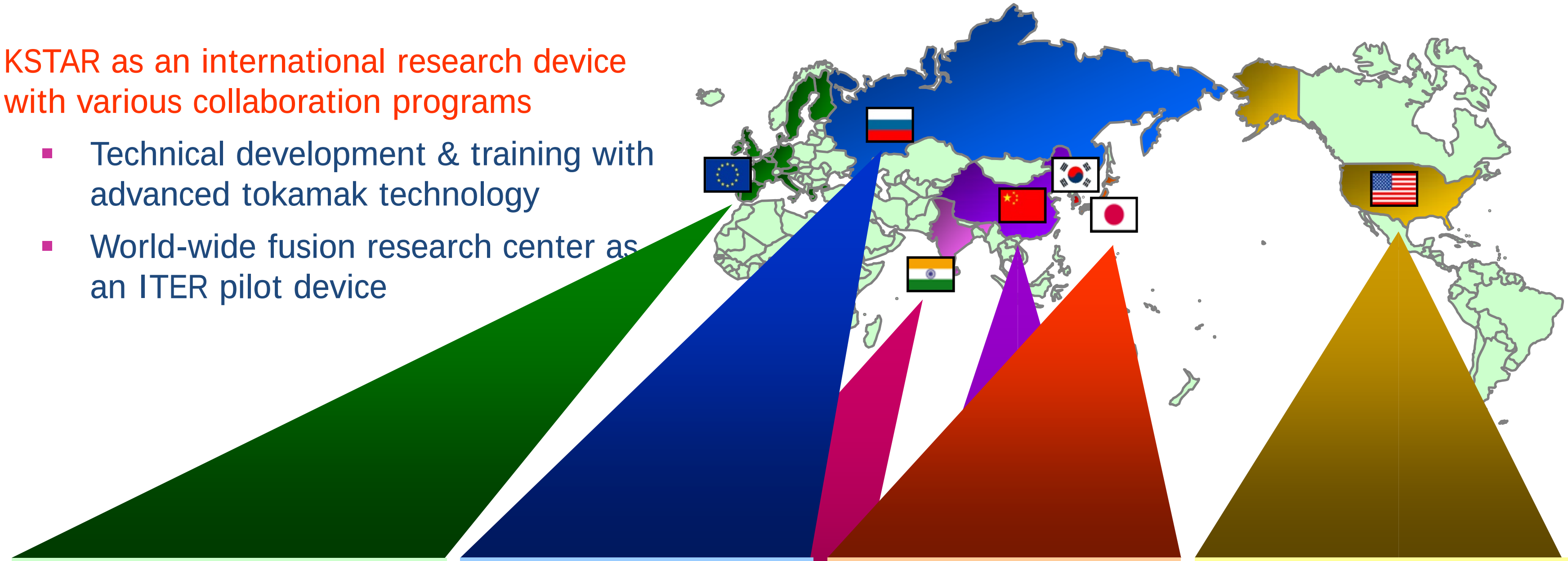
Plasma Edge Research Center

Divertor
PFC
Edge Diagnostics



International Collaboration

- KSTAR as an international research device with various collaboration programs
  - Technical development & training with advanced tokamak technology
  - World-wide fusion research center as an ITER pilot device



EU

IVCC technical design
D-T neutronics
NBI
Safety & risk management for ITER
Steady-state technology
PFC cooling
LHCD
Cryogenics
Divertor for steady-state operation

RUSSIA

SC coil design
SC tokamak commissioning
Hard X-ray diagnostics
SC tokamak startup
Machine safety

INDIA

Heating device
SC device operation
Diagnostics

JAPAN

NBI development
Bolometry diagnostics
Thomson laser system
ITER-like 170GHz gyrotron
Motor generator
ECH technology
Cryogenics
Diagnostics

CHINA

SC & control coil PS
SC device operation
Bilateral Workshop

USA

Plasma control system
ECCD launcher R&D, LHCD
AT-simulation, stability analysis
Visible Filterscope
Thomson, MSE/CER/BES R&D
High-speed plasma control
Control coil PS
Long-pulse ECH / ECCD, ICRH
Remote operation R&D
Integrated AT-mode simulation
Fusion Grid
NBI diagnostics (MSE/CER/BES)
MIR / ECEI
Operation extent R&D

* KSTAR Progress
* KSTAR Collaboration Interest

Summary

- KO fusion program was selected as one of green technologies for targeted support by the KO Government.
- KSTAR device construction, the integrated commissioning and 1st plasma startup was accomplished on June 13, 2008. The operation plan in the first phase was aimed at achieving controllability for shaped, high performance plasmas in super-conducting device.
- The operation results of the KSTAR device could be important technical basis for the fusion researches including ITER.
- KO-DA for ITER starts making progress in procurement process and R&D.
- Stronger collaborations are expected among institutes utilizing KSTAR to promote the fusion science and technology. It is desired that specific areas should be focused for international collaboration.